TOPOLOGY AND INDIVIDUAL LOCATION OF CROWDS AS MEASURES OF EFFECTIVENESS FOR NON-LETHAL WEAPONS

Gordon Cooke*; Elizabeth Mezzacappa, PhD; Charles Sheridan; Robert DeMarco;
Kevin Tevis; Kenneth Short, PhD; Gladstone Reid; Nasir Jaffery; and John Riedener
US Army Target Behavioral Response Laboratory
Picatinny Arsenal, NJ 07806

ABSTRACT

A quantitative analysis method for crowd responses to non-lethal weapons (NLWs) has been developed. Using motion capture technology, the location and orientation of all individuals in a crowd were recorded during various engagements with a control force wielding simulated NLWs. The motion and behavior of the group, both as a whole and as individuals, were quantified using a variety of metrics derived from these measures. Several of the proposed metrics (average leading edge and streamlines) were sensitive to differences in critical characteristics of the scenario, such as weapon type (standoff vs. hand-to-hand combat) and rules of engagement (threat vs. no threat). Therefore, these metrics can be used to assess and compare effectiveness of different types of non-lethal weapons and systems and how weapon effectiveness varies with tactics, techniques, and procedures.

1. INTRODUCTION

Crowd management may be the prototypical military scenario that requires the use of non-lethal weapons. To prevent and manage possible crowd disturbances, non-lethal weapons need to be developed with tactics, techniques and procedures (TTP) for employment. However, to accomplish this goal, there must be a way to judge the effectiveness of different non-lethal weapons. Judgment of effectiveness requires understanding of both the behaviors that the war-fighter wants to induce using a non-lethal weapon and the crowd behaviors that will result from weapon use. To the first point, an examination of commands typically given to crowd members involve controlling their whereabouts—"Stay back!", "Leave!", or "Stay!". Therefore, the effectiveness of a non-lethal weapon should be based on how well the use of the weapon or TTP controls the location and movement of crowd members.

Decisions of the effectiveness of non-lethal weapons in crowd situations require methods to measure crowd response to non-lethal weapons. Then these measures can be compared against these desired responses. In other words, the primary question of effectiveness is: "did the crowd do what the Soldier wanted them to do when the weapon or TTP was used?" Then the question of comparative effectiveness becomes: "does one weapon or TTP accomplish this better than another?"

Metrics of crowd responses are necessary in order to conduct analyses comparing effectiveness of one non-lethal weapon or system with another. An exploratory series of behavioral experiments were undertaken to fulfill this requirement. The goal was to develop methods that describe critical crowd behavioral response relevant to the military's mission, namely location, orientation, and locomotion of persons in the crowd.

This paper describes the mathematical methods investigated to quantitatively describe crowds, group behavior of the crowd, and individual locomotion within the crowd. These methods are fundamental to the analysis of effectiveness of non-lethal weapons in crowd scenarios.

1.1. Conceptual Framework

The Target Behavioral Response Laboratory (TBRL) program of Crowd Behavior research utilizes the Field Theory as expounded upon by Kurt Lewin (1935, 1936), as a framework that guides design, conduct, and analysis of experiments. Predictions of the areas or goal regions to which people move can be made based on the tenets of field theory. Very briefly, Lewin conceptualized goal regions as having positive and negative valences. People locomote towards "positive valence goal regions" and locomote away from "negative valence goal regions". These valenced goal regions give rise to psychological tensions, psychological forces, and then locomotion. People are attracted to positive valence goal regions and thus attempt to move toward such regions.. Conversely, people are repulsed from negative valence goal regions and thus attempt to move away from such regions.. Therefore, the very vocabulary arising from Field Theory makes this conceptual orientation useful in terms of predicting how non-lethal weapons move crowds. Moreover, the concepts of attraction and repulsion allow for the use of standard methods for vector analysis from engineering and physics. Thus, vector field maps can be used to render forces arising from positive and negative valence goal regions in fields of attraction and fields for repulsion graphically.

Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **29 NOV 2010**	2. REPORT TYPE **Conference Proceedings Paper**	3. DATES COVERED **00-00-2008 to 00-00-2010**
4. TITLE AND SUBTITLE **TOPOLOGY AND INDIVIDUAL LOCATION OF CROWDS AS MEASURES OF EFFECTIVENESS FOR NON-LETHAL WEAPONS Excerpted from the Proceedings of the 27th Army Science Conference, 29 November ??? 2 December 2010.**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Gordon Cooke; Elizabeth Mezzacappa; Charles Sheridan; Robert DeMarco; Kevin Tevis**		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army, ARDEC, Target Behavioral Response Laboratory,RDAR-EIQ-SD,Building 3518,Picatinny Arsenal,NJ,07806-5000**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **The other authors are Kenneth Short, Gladstone Reid, Nasir Jaffery, and John Riedener.**		

14. ABSTRACT

A quantitative analysis method for crowd responses to non-lethal weapons (NLWs) has been developed. Using motion capture technology, the location and orientation of all individuals in a crowd were recorded during various engagements with a control force wielding simulated NLWs. The motion and behavior of the group, both as a whole and as individuals, were quantified using a variety of metrics derived from these measures. Several of the proposed metrics (average leading edge and streamlines) were sensitive to differences in critical characteristics of the scenario, such as weapon type (standoff vs. hand-to-hand combat) and rules of engagement (threat vs. no threat). Therefore, these metrics can be used to assess and compare effectiveness of different types of non-lethal weapons and systems and how weapon effectiveness varies with tactics, techniques, and procedures.

15. SUBJECT TERMS

non-lethal weapons, crowd, motion capture, effectiveness metrics, control force, human behavior, human experimentation, Target Behavioral Response Laboratory.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Public Release**	**8**	

We can use these vector methods in comparing effectiveness of non-lethal weapons in that we can compare the recorded negative repulsive forces arising from the Soldier wielding the weapon or the area of impact. The stronger the measured negative force field, the more effective the weapon. This comparison is valid regardless of the type of energy or weapon used.

The work described in this report applies principles and methods of physics and engineering to psychological theory to test and analyze crowd behavior. From these analyses, we can derive mathematical models for prediction of crowd response to non-lethal weapons fire, which, in turn, can be imported into modeling and simulation endeavors.

2. METHODS, ASSUMPTIONS AND PROCEDURES

This study was performed at the Target Behavioral Research Laboratory, Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ under a DoD-wide Assurance signed by the Surgeon General for Force Protection. The protocol for use of human subjects was approved by the ARDEC Institutional Review Board.

2.1. Setup

The Crowd Behavior Testbed is a 6,000 square foot facility housed in the TBRL (see Cooke et al. 2007). The laboratory is fully equipped with a comprehensive suite of computer controls for automation, data recording and audio/video presentation and recording. The primary test area is 50 feet square with overhead trussing for mounting cameras and other hardware, and a padded floor. This area is a motion capture (MOCAP) space using a 24 camera Vicon V8i system.

A set of 20 construction helmets was outfitted with seven to nine reflective markers each (Figure 1). This allowed the MOCAP system to record the location and orientation of the subjects heads as six degree-of-freedom data. Control Force members were also outfitted with reflective markers (Figure 2).
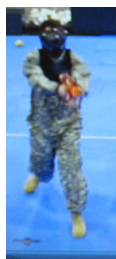

Figure 1: Subject helmet   Figure 2: Control Force

The human subjects were given a task of throwing a beanbag into one of three available targets that were placed on the opposite side of the testbed. Beanbags were numbered with the subjects' numbers. After each trial, researchers recorded whether a subject's beanbag hit the target, missed the target, or was not thrown. To increase their motivation, the subjects were given points if they were able to get their beanbag into a target. This task by itself was shown not to be very difficult.

Three targets were placed on the front, middle and rear of a military pickup truck (M1008 CUCV) on the goal end of the field. A start/quit line was placed on the floor at the opposite end of the field, allowing enough room for subjects behind the line to be inside of the MOCAP area. Barriers and boundary lines on the floor were placed along the sides of the field to ensure that subjects remained inside of the MOCAP area.

2.2. Method

Data for these analyses were drawn from a larger study described elsewhere (Cooke, 2009; Mezzacappa et al. 2009a,b). Groups of 7 to 19 adult subjects were used to represent the crowd. Subjects were recruited from the general public and paid $20/hour for participation.

Subjects performed a task that simulated the tactical construct of a crowd facing an area protected by a control force. The scenario conforms to the Counter Personnel task #1 (deny access to an area) as outlined by the Joint Capabilities Document for Joint Non-Lethal Effects (DoD, 2007). The control force (for these analyses, a single individual) used either hand-to-hand combat weapons (foam batons) or stand-off projectile weapons (toy gun with foam projectiles) (Figure 3) and also had two different notional Rules of Engagement (ROE). Under the threat ROE, the control force actively tried to tag the crowd members in order to keep them away from the targets. In the no-threat ROE the control force did not tag the crowd members but were allowed to move around the field to try and keep the crowd back simply by their presence. In addition, baseline trials were included where there were no control forces present.

Figure 3: Simulated weapons

The crowd members were each given one beanbag. If the subject could get the beanbag into any of the targets at the far end of the field then the group was rewarded with points and money. Individual points were also tracked with bonus money for the individual with the best

score. This was intended to create a positive valance goal at the target end of the field. The control force, however, could tag the subjects on the way to the targets which resulted in a loss of points and money for the group. Thus, the control force members represented a negative valance goal that was intended to create a repulsive force. More simply, the scenario was designed to induce subjects to go towards targets and to go away from the control force.

A variety of metrics that could describe a crowd were developed and some are described below. Any of these proposed metrics are expected to be sensitive in some way to changes in environmental conditions around the crowd. This effort was mainly exploratory in nature.

Patterns of locomotion were expected to differ depending on the type of weapon (hand-to-hand vs. stand-off) and the simulated ROE (threat vs. no threat). It was expected that the threat condition would induce a much larger repulsive force than the no-threat condition. The no-threat condition was expected to have some level of effect due to the presence of the control force, even though the weapons were not employed. The hand-to-hand weapon was anticipated to have less repulsion than the stand-off weapon due to the shorter range of the hand-to-hand weapon.

2.3. Crowd Metrics

A variety of possible measures and metrics that could be derived from location and time data were investigated to determine their potential for describing the state and behavior of both crowds and individuals in a crowd. These were developed based on doctrine (FM 3-07.22, FM 3-07.31, FM 3-19-15) and test plans for simulations to study crowds (AEgis Technologies Group, 2007) with additional metrics added from in-house brainstorming. Methods for mathematically describing a crowd were informed by concepts from fluid mechanics and solid dynamics, e.g., using a weighted centroid as a measure of centrality..

The position and orientation data recorded by the Vicon MOCAP system and used here can be described by three matrices: $X_{t,S}$, $Y_{t,S}$, $\theta_{t,S}$, where t is the time step and S is an individual subject from a set of N total subjects. Three separate variables were used to describe the same information for the control force member(s): $\overline{X}_{t,C}$, $\overline{Y}_{t,C}$, $\overline{\theta}_{t,C}$, where C is the control force member (when multiple control forces are used).

In this study, the coordinate system of the raw data was defined with the origin in the center of the testbed and the positive Y-axis in the direction of the crowd's goal (Figure 4). Time zero for all trials was defined as the time when the first subject crossed the start line location.

For best results, a start line location about 0.5 meters forward of the actual line on the ground was used in order to account for subjects who stood very close to the start line and may have been leaning their heads over the line without crossing it.
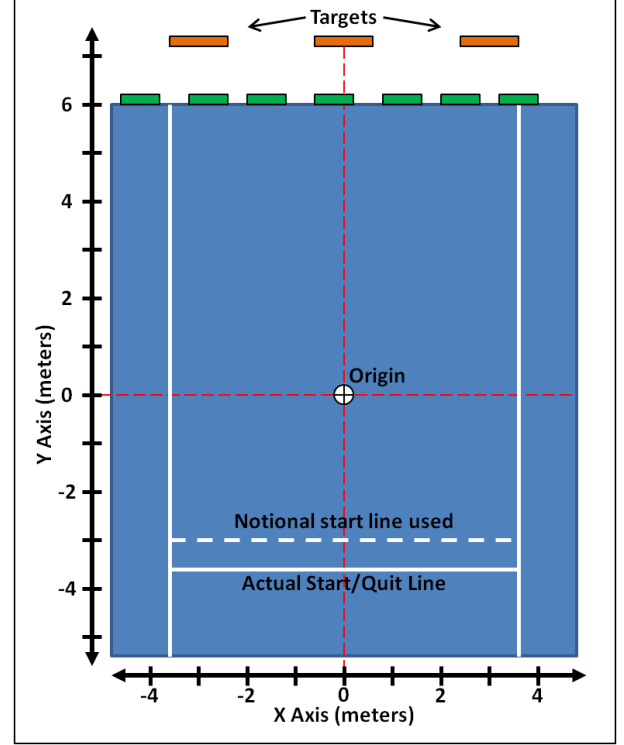

Figure 4: Coordinate system and layout

2.4. Individual Measures

Velocity of an individual ($V_{t,S}$) can be obtained by dividing the distanced traveled ($D_{t,S}$) by the time interval. The distance traveled in a time step is described by:

$$D_{t,S} = \sqrt{\left(X_{t+1,S} - X_{t,S}\right)^2 + \left(Y_{t+1,S} - Y_{t,S}\right)^2} \qquad (1)$$

$$V_{t,S} = \frac{D_{t,S}}{\Delta t} \qquad (2)$$

The interpersonal distance (ID) between any two individuals (Sa and Sb) can also be calculated:

$$ID_{t,Sa,Sb} = \sqrt{\left(X_{t,Sa} - X_{t,Sb}\right)^2 + \left(Y_{t,Sa} - Y_{t,Sb}\right)^2} \qquad (3)$$

Similarly, the distance between each person and the control force member was also calculated:

$$CFD_{t,S} = \sqrt{\left(X_{t,S} - CFX_t\right)^2 + \left(Y_{t,S} - CFY_t\right)^2} \qquad (4)$$

The location of the subject can also be expressed as the distance from the center of the group, i.e., radius.

Calculation of the geometric center and centroid are discussed below. In this discussion, the preference is to use the centroid. The individual radius can be described by:

$$r_{t,S} = \sqrt{\left(X_{t,S} - C_t\right)^2 + \left(Y_{t,S} - C_t\right)^2}$$ (5)

2.5. Crowd Measures

Geometric Center and Centroid

The geometric center (GC) of the crowd is the central point of the area the crowd occupies. In contrast, the centroid (C) of the crowd is the central tendency of all members of the crowd, i.e., the average location. This is not generally the same as the geometric center as the centroid is weighted toward the bulk of the crowd and is less influenced by an individual who is separated from the group (Figure 5).
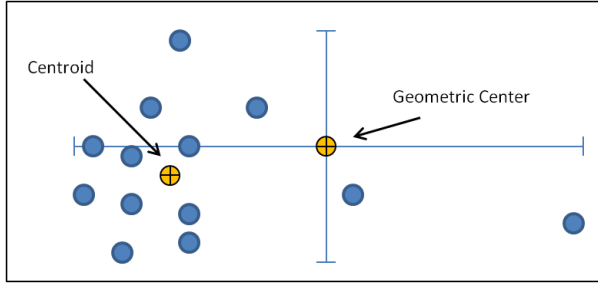
Figure 5: Geometric center vs. centroid

$$GC_t = \left(\frac{\max(X_t) + \min(X_t)}{2}, \frac{\max(Y_t) + \min(Y_t)}{2}\right)$$ (6)

$$C_t = \left(\frac{\sum_{S=1}^{N} X_{t,S}}{N}, \frac{\sum_{S=1}^{N} Y_{t,S}}{N}\right)$$ (7)

Dispersion

The average radius $\overline{R}$ can be derived from the radii of the individuals of the group. This dispersion measure describes how spread out or clustered the group is.

$$\overline{R_t} = \frac{\sum_{S=1}^{N} r_{t,S}}{N}$$ (8)

The area (A) of a circle that is the best fit for the area covered by the crowd can be expressed by using the average radius. This measure may be useful to help visualize the area taken up by a given crowd, but it is not an absolute measure of the actual area. This measure does not add much from an analytic standpoint as it simply mirrors the average radius measure.

$$A_t = \pi \cdot \overline{R_t}^2$$ (9)

Leading and Trailing Edge

The leading edge (LE) and trailing edge (TE) are the front and back of the crowd, respectively. The leading and training edge were defined by the individual crowd member who was farthest to the front or rear along the axis of approach. In this study, these were defined by the maximum and minimum values along the Y-axis because the coordinate system was defined with the Y-axis towards the goal. In other situations a coordinate transform may be necessary.

$$LE_t = \max(Y_t)$$ (10) $$TE_t = \min(Y_t)$$ (11)

Likewise, the closest distance between any individual and the control force (CF_close$_t$) member is calculated for each time step.

$$CF\_close_t = \min(CFD_t)$$ (12)

Density

The bulk density of a very large crowd would most likely not be useful because crowds are seldom homogenous. Local densities of groups within the crowd, however, could be useful. All subjects were considered as one group rather than a large crowd due to the size (N) of the groups in the study. Density (Dens) could be described simply as the number of people within a given area. In this case the area (A) used is the area of a best fit circle as described above.
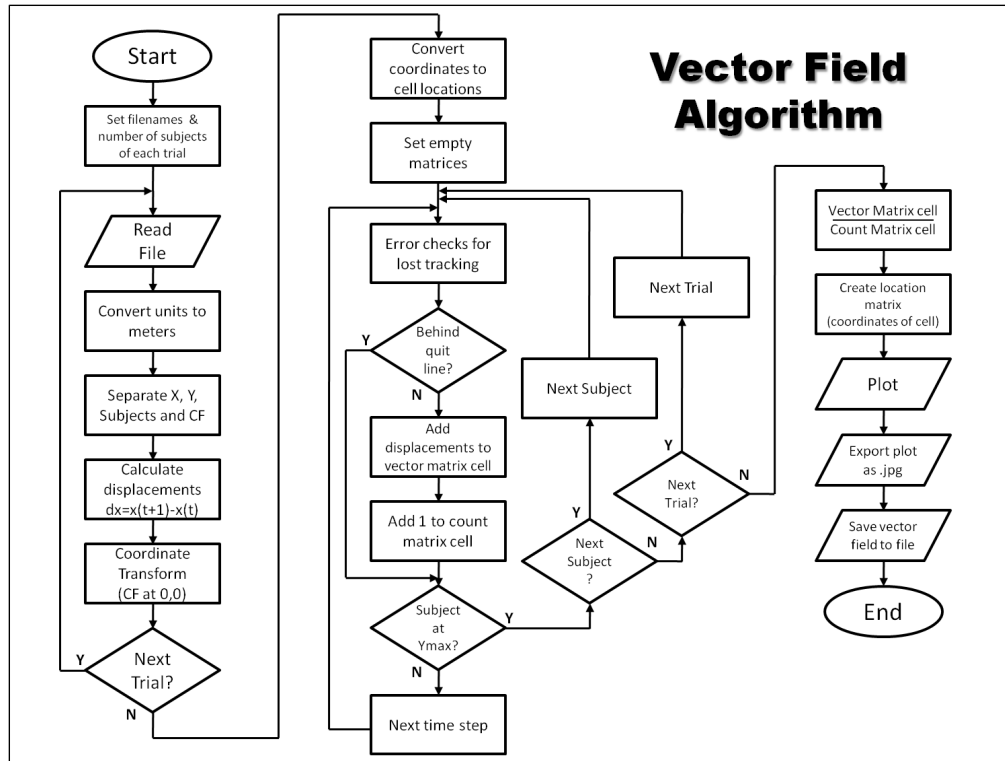
$$Dens_t = \frac{N}{A_t}$$ (13)

Figure 6: Vector field algorithm flow chart

2.6. Vector Fields

The movement data captured in this study was also used to see if Lewin's Field Theory of behavior could be used to understand an individual's real movement toward a positive valance goal and away from a negative valance goal. The data from each individual subject was processed to create vector field maps of the topology presented in the experimental situation (Figure 6). For the baseline trials, with no control force present, the vector field was created for the experimental area. For the rest of the trials, the vector field was created as a field around the control force member.

To create the vector fields, each subject was considered separately. First, the movement vector of each subject was calculated for each time step. A coordinate transformation was then performed on each subject's location to a new coordinate system using the control force member as the origin. The area of the field was then divided into cells. Each data point (one subject in one time step) was then added into the cell that the transformed location belonged to. The resulting vector for each cell was the mean of all vectors for that cell.

Data was only considered for the approach towards the targets (goal). In this way, the only data considered is for a situation where the subject wants to move towards a positive valance goal and has an impeding negative valance goal. After throwing their beanbag, which was assumed to occur at, or near, closest approach, the subject's goals shifted to returning to the quit line, as the target no longer has valance.

For ease of understanding, the resulting vector fields were used to create streamlines. Each streamline shows the expected path of an object (in this case a person) from the beginning of the streamline.

3. RESULTS AND DISCUSSION

This experiment investigated how the behavior of a crowd or group of multiple individuals could be expressed numerically. The following are the descriptive statistics derived from this experimental work. The data set used included 90 trials of data recorded from 5 groups, each made up of 12-17 individuals.

3.1. Baseline

Figure 7 shows the changes in centroid, leading edge, and dispersion measure over time during the baseline (no control force present) trials. Each trial is represented by a separate line. The abscissa represents time. For the lead edge and centroid graphs (Figure 7a and Figure 7c), the ordinate represents Y-axis location on the testbed, with 0 as midway between the start line and the targets. For the dispersion graph (Figure 7b) the ordinate represents the average number of meters each individual was from the center of the crowd.

Baseline trials were very similar across trials and across groups. The leading edges (Figure 7a) and the centroids (Figure 7c) of the groups had very similar slopes during the approach to the goal and the return. Similar slopes indicate similar velocities. The "linger" time while the crowd was closest to the goal was also very similar across groups and trials.

The dispersion, measured as average radius from the centroid, also showed similarities across trials and groups (Figure 7b). The apparent pattern has two peaks with the second one being larger than the first. The crowd begins moving in the same direction and dispersion increases due to differences in individual speed. Then the dispersion decreases as individuals move towards each other (faster people are returning to the start line while others are still approaching the goal) until it begins increasing again when the bulk of faster and slower individuals pass each other in opposite directions. Finally, the dispersion peaks with the last individuals still at the goal and the fastest waiting back at the start line.
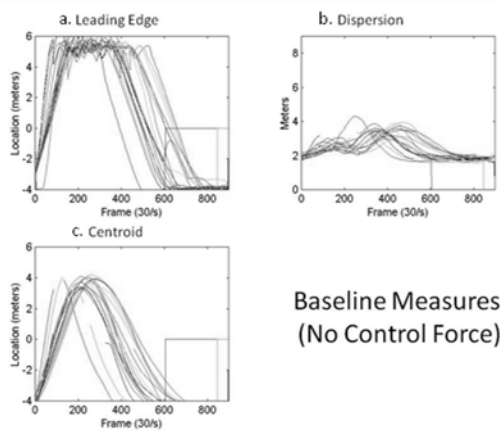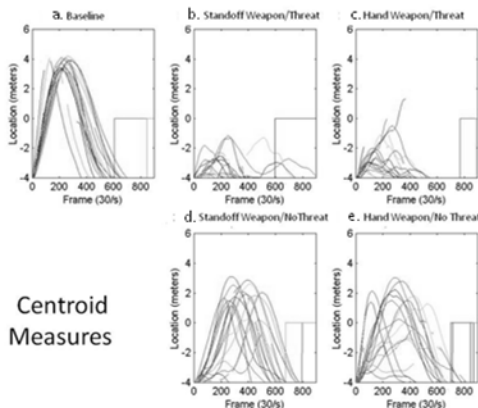

Figure 7: Baseline condition metrics

Figure 8: Centroid comparison of conditions

3.2. Changes in Centroid

Suppression effects are clearly shown in Figure 8. Figure 8 presents the changes in centroid location in the testbed under the baseline (Figure 8a, identical to Figure 7c), under threat conditions (Figure 8b and Figure 8c) and under no threat conditions (Figure 8d and Figure 8e). 0 on the ordinate (Y-axis location) denotes the center of the testbed, with -4 at the start/quit line and +6 the targets.

This measure seems sensitive to the control force presence and activities. The presence of the control force seems to shift the peak of the centroid back about 1.5 to 3 meters. The use of weapons by the control force moves the peak centroid by 5 to 7 meters.

3.3. Changes in Leading Edge

In addition to graphs of the type shown above, the average leading edge can be obtained by combining the data from all the trials (Figure 9). This mean performance curve shows how the behavior changed in a general sense. It can be seen that the two non-threat conditions are very similar, not allowing the leading edge quite as far forward and slightly delaying the advance, as well as the delaying the retreat. It can also be seen that in the threat conditions there is a much lower peak of advance and almost no linger time at the closest approach. Under threat, the standoff weapon (green line) seems to keep the leading edge slightly further back than the hand weapon (red line).
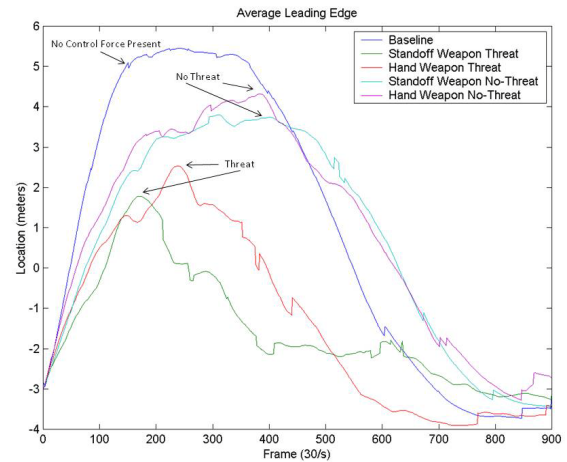

Figure 9: Average leading edge for each condition

3.4. Changes in Dispersion

The metric of the crowd dispersion, defined as the average radius from the centroid, seems very repeatable across groups and trials for both the baseline (Figure 10a) and the threat cases (Figure 10b and Figure 10c). The rate at which the crowd spread out and coalesced at the start and end of the trials was also very similar between trials of the same type.

During non-threat trials, however (Figure 10d and Figure 10e), the dispersion grew with peaks generally over 4 meters and as high as 8 meters. It is interesting to

note that the non-threat trials seemed to follow one of two trends: one similar to the baseline trials two-peak curve, and the other similar to the threat trials single peak. It is unknown if this is a result of different tactics used by the control force or different tactics used by the crowd.
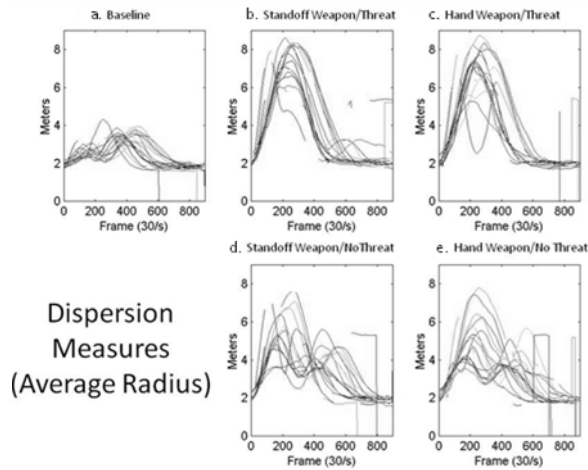

Figure 10: Dispersion comparison of conditions

3.5. Vector Fields

Figure 11 shows the baseline vector field and the corresponding streamline graph (Figure 12). In this graph, the top represents the area of the targets, the bottom the area of the safe line. The three goals on the edge of the area seem to create a linear attractive goal (equal across the width of the area) except at the final 2 meters when the locomotion deviates toward a specific goal as indicated by the curving of the lines near the targets. There are no goals varying along the x-axis and the result shows little variation in this direction of the field.
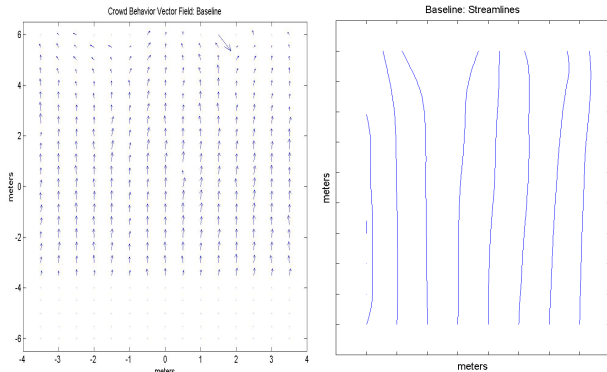

Figure 11: Baseline vector field

Figure 12: Baseline streamlines

Vector fields were created for each weapon/ROE condition. The baseline vector field, which is due to the positive valance of the targets, was also subtracted from these to find the vector field due to the negative valance

of the control force. Streamlines will be presented here in place of vector fields.

Figure 13 (hand weapon) and Figure 14 (standoff weapon) show the streamlines when the control force ("CF" in the diagrams) is present, but no shots are fired and no tags are made. In the non-threat conditions, the vector field shows that subject locomotion is still towards the target, but there is a motion around the control force member.
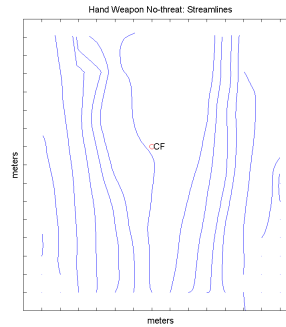

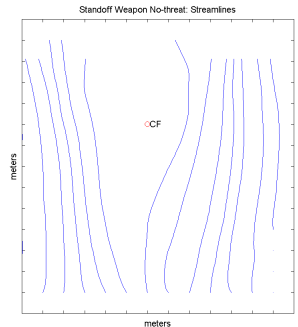Figure 13: Hand weapon no-threat streamlines

Figure 14: Standoff weapon no-threat streamlines

Figure 15 (hand weapon) and Figure 16 (standoff weapon) show the streamlines when the control force ("CF" in the diagrams) is present, and shots are fired and tags are made resulting in loss of points and money for subjects. The streamline plots of the two threat conditions reveal strong evidence of avoidance behaviors. This effect is depicted by the bending of the streamlines around the Control Force, which indicates the presence of strong forces along the X-axis that are side-to-side across the testbed.

It is interesting that the width (on the X-axis) of the flow, for 1 meter streamlines, around the control force is roughly the same for both weapons (about 4 meters). The range at which this divergence begins (in the Y-axis) is shorter for the hand weapon compared to the standoff weapon. This is likely related to the range of the weapon.
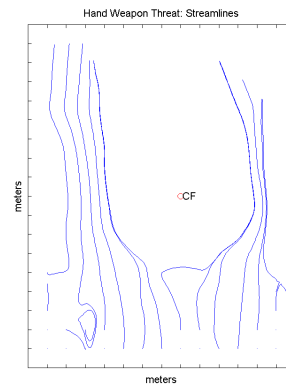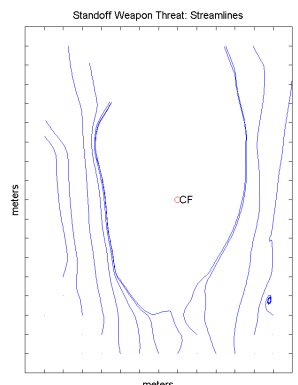

Figure 15: Hand weapon threat streamlines

Figure 16: Standoff weapon threat streamlines

4. CONCLUSIONS

The methods presented here are critical to investigating the effectiveness of non-lethal weapons in crowd-control force scenarios.

The metrics presented here showed consistency across trials and between groups. The centroid of a group tracked over time showed distinguishable differences between the different conditions of the experiment and is sensitive to the weapon and tactics used. The average leading edge (averaged over all trials) does appear to show the difference in the different conditions of weapon and threat level. Using the average leading edge seems to be a more meaningful metric than leading edge alone due to the variability between individual trials.

The highest dispersions were observed under the no-threat conditions. The dispersion metric may be less meaningful for directly assessing weapon effectiveness (is high or low dispersion more desirable?) but appears a very good measure for characterizing the behavior of the group.

Vector field methods of analyzing the motion show much promise and it is very likely that the behavior of human locomotion can be explained using literal interpretations of Lewinian Field Theory. It was possible to quantify the attractive field of the positive valance goal. It was also possible to create vector fields of the observed locomotion under various combined positive and negative goal conditions. The derived vector field for the negative valance goal conditions alone (by subtracting the underlying positive valance goal behavior from the combined) seems to provide reasonable results, although further testing and analysis is required due to noise in the current data.

Vector field analysis can be used in simulations to predict whether a crowd will stop approach, leave an area, or stay in response to a non-lethal weapon or system. It can also be used to predict whether they will move slowly or stampede. The vector field information could also be used to determine where to place control force personnel, barriers or weapons for effective control of a crowd. The results of the tests provide preliminary evidence that these crowd metrics have face validity, are reliable, and are sensitive to important situational parameters. Therefore, these metrics can be used to assess and compare effectiveness of different non-lethal weapons and systems and their tactics, techniques, and procedures.

REFERENCES

AEgis Technologies Group, 2007: Active Denial System Advanced Concept Technology Demonstration Crowd Simulation: Verification & Validation Assessment and Accreditation Recommendation Report. AEgis Technologies Document No. EJ-SETAC-07-RP002, 26 pp. [available thru USAF Force Protection Battlelab]

Cooke, G., E. Mezzacappa, and K. Yagrich, 2007: Development of the Crowd Behavior Testbed. TBRL-NLE-TR-07011, 30 pp.

Cooke, G., and Coauthors, 2009: Crowd Simulation Volume III: Topology and Individual Locations of Crowds. TBRL-NLE8-TR09007, 35p.

Department of Defense, 2008: *Joint Capabilities Document for Joint Non-lethal Effects*. Washington, DC, 77 pp.

Headquarters, Department of the Army, 2003: *FM 3-07.31/MCWP 3-33.8 / AFTTP(I), 3-2.40: Peace Ops: Multi-service Tactics, Techniques, and Procedures for Conducting Peace Operations*. Army Publishing Directorate, 183 pp.

Headquarters, Department of the Army, 2004: *FM-3-07.22: Counterinsurgency Operations*. Army Publishing Directorate, 178 pp.

Headquarters, Department of the Army, 2005: *FM 3-19-15: Civil Disturbance Operations*. Army Publishing Directorate, 253 pp.

Lewin, K., 1935: *A Dynamic Theory of Personality*. McGraw-Hill, 286 pp.

Lewin, K., 1936: *Principles of Topological Psychology*, New York: McGraw-Hill, 231 pp.

Mezzacappa, E., and Coauthors, 2009a: Crowd Simulation: Volume 1- Operational Requirements. TBRL-NLE8-TR09002, 42p.

Mezzacappa, E., and Coauthors, 2009b: Crowd Simulation Volume II: Effects of Control Force Number, Threat, and Weapon Type on Crowd Behavior. TBRL-NLE8-TR09003, 27p.